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Effect of operating conditions on the yield and quality of açai (*Euterpe oleracea* Mart.) powder produced in spouted bed

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ABSTRACT

Açai is a nutritious and energetic food that demonstrated antioxidant activity and cardioprotective properties. However, since açai is a very perishable raw material, studies for its preservation are needed. The açai powder production is a way to obtain products with low moisture content, good stability and higher shelf life. This study aimed to investigate the feasibility of drying açai in spouted bed, evaluating the operating conditions on the yield and quality of the product. The experiments were conducted according to a central composite design. Operating variables studied were: drying air temperature, airflow rate and maltodextrin concentration. Process yield, moisture content and total anthocyanins content were analyzed as responses. The process yield was positively influenced by all the variables studied. The increase in temperature caused a significant reduction in the moisture content. Airflow rate was the variable that most influenced the degradation of anthocyanins. Applying desirability function method, an optimal drying condition was found. Such this conditions was obtained a nutritious, energetic and porous powder, with excellent flowability, low moisture and high anthocyanins content.

1. Introduction

Euterpe oleracea Mart. is a palm tree that occurs in the North of Brazil, with a high socioeconomic importance for the Amazon region. Its fruits are spherical, constituted by a slightly hard seed, involved by a greyish, oleaginous pulp, covered by a dark purple epidermis. From such fruits, the açai pulp is obtained; a product with high energetic value, nutritive potential, with high fiber content, proteins, lipids and anthocyanins (Rogez, 2000; Schreckinger, Lotton, Lila, & Mejia, 2010).

The interest in such product has grown in Brazil and also in the world, due to different benefits associated with its consumption, specially for the human health, such as a high antioxidant capacity (Hassimotto, Genovese, & Lajolo, 2005; Hogan et al., 2010; Jensen et al., 2008; Mertens-Talcott et al., 2008; Rogez, 2000; Schauss et al., 2006; Schreckinger et al., 2010), anti-inflammatory (Jensen et al., 2008) and anti-proliferative activity (Hogan et al., 2010), ability to assist in the reduction of the proliferation of leukemic cells (Pozo-Insfran, Percival, & Talcott, 2006). It is also indicated to assist in the treatment of heart diseases (Rocha et al., 2007) and cholesterol (Souza, Silva, Oliveira, & Pedrosa, 2010). However, açai is a highly perishable food (Rogez, 2000), studies are necessary for its preservation.

The production of açai powder is a way to create products with low moisture content, excellent stability and longer shelf life. Different techniques are used to produce fruit powder. In the literature, there are several papers related to açai powder produced by freeze drying and spray drying. The freeze-dried açai powder is a high-quality product (Gallori, Bilia, Bergonzi, Barbosa, & Vincieri, 2004; Schauss et al., 2006); however, this process has high costs. In relation to the açai powder produced by spray drying, the high lipid content in the açai pulp leads to problems during this process, causing incrustation of the spray nozzle. Tonon, Brabet, and Hubinger (2008) filtrated the açai pulp previously in order to reduce the lipid content and obtained satisfactory results for the powder formation by spray drying. However, filtrating the açai pulp causes losses that interfere in its nutritional value.

Drying fruit pulp in spouted bed with inert particles has been

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largely studied in Brazil over the last decades. This process is considered as an alternative to spray drying, since it leads to similar quality products at significantly lower investment costs. In addition, it is possible to perform the drying of thermosensitive materials, because the average temperature of the particles is lower than the average temperature of the drying air. In this process, the paste is inserted into the spouting bed continuously or intermittently, and it covers the inert particles creating a film. After the paste adheres the surface of the inert particles, the film becomes dry and breakable. Collisions between the inert particles and with the walls of the equipment promote enough energy to break the film, which becomes loose and is carried through the air, and collected by cyclones (Freire, Ferreira, & Freire, 2011; Rocha & Taranto, 2008; Strumillo & Kudra, 1986).

The aim of this paper was to study the açai drying process on a spouted bed using inert particles, evaluating the influence of operating conditions on the yield and quality of the product.

2. Materials and methods

2.1. Materials

The açai pulp was obtained in the commercial region of Belem (State of Para, Brazil). The açai pulp was stored in a freezer at approximately−18 °C, and it was unfrozen according to the necessary amount for each experiment.

Maltodextrin MOR-REX 1910 (Ingredion Brasil Ingredientes Industriais Ltda., São Paulo, Brazil) was added to the açai pulp to assist in the powder formation.

2.2. Sample preparation and characterization

Before each experiment, the açai pulp was unfrozen and diluted with distilled water at 2:1 (w/w). Then, maltodextrin was added according to the required amount for each experiment. The paste was passed through a colloid mill during approximately 5 min in order to reduce the suspended solids, avoiding the incrustation of the spray nozzle.

2.3. Drying equipment

Açai-maltodextrin paste was dried in cone-cylindrical spouted bed with the following dimensions: cylindrical column with 0.20 m of diameter and 0.30 m of height, 60° conical base angle, 0.14 m of height and inflow air diameter of 0.03 m. The scheme of the experimental system that was used in this work is shown in Fig. 1. The pressure measure on the bed was obtained through a differential pressure transmitter (Cole Parmer, model 68014-18, with reading range from 0 to 6229 Pa, and response time of 250 ms). The inlet air temperature was measured by a type-K thermocouple and controlled by a PID controller (NOVUS, N1200). The temperature and the relative humidity of the air were monitored during the experiments using two thermo-hygrometers (NOVUS, RHT-XS) installed on the entry and exit points of the bed. A peristaltic pump (Cole Parmer, model 7518-10, Masterflex L/S type) was used to transport the paste to the spray nozzle. The paste was kept under stirring, using a magnetic stirrer. It was inserted on the bed intermittently, for three times, under intervals of 10 min. The total mass of the atomized paste in each experiment was approximately 0.30 kg. The atomization pressure used was approximately 135.83 kPa, and the feeding flow was 10.0 mL min^{-1}. The powder produced was collected by a cyclone, built from stainless steel, located on the top of the spouted bed.

The inert particles used in the spouted bed were high-density polyethylene (diameter of 3.09 mm and density of 899.5 kg m^{-3}). Fluid dynamic tests were conducted to determine the spout airflow rate and assure stable hydrodynamic conditions. Minimum spouting airflow (Qms) and maximal pressure drop (ΔPm) were obtained from the fluid dynamic curve of bed pressure drop as a function of airflow rate, employing a fixed load of high-density polyethylene particles of the 0.80 kg.

2.4. Statistics and experimental design

A central composite design was used for the spouting bed açai drying study. The operating variables studies were: drying air temperature (55, 65 and 75 °C), airflow rate (1.2, 1.25 and 1.30 × Qms) and maltodextrin concentration (15, 20 and 25% w/w). Such variables were codified as X_1, X_2 and X_3, respectively.

The analyzed responses were: process yield (Y), final moisture content of the powder (MC) and total anthocyanin content (AC). The process yield was obtained from Eq. (1), which represents the ratio between the total powder mass collected in the cyclone (m $powder$) and the total mass added to the bed during the experiment (m $paste$), both on a dry basis.

$$Y = \frac{m_{powder}\left(1 - MC_{powder}\right)}{m_{paste}\left(1 - MC_{paste}\right)} \times 100 \tag{1}$$

The central composite design allowed us to build second-degree polynomial models that were built according to Eq. (2), in which y are the analyzed responses (dependent variables); X_1, X_2 and X_3 are the codified operating variables (independent variables); β_0 is a constant; β_1, β_2 and β_3 are the regression coefficients for the linear terms; β_{11}, β_{22} and β_{33} for quadratic terms; β_{12}, β_{13} and β_{23} for interaction terms.

$$\begin{aligned} y = {} & \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 \\ & + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 \end{aligned} \tag{2}$$

The statistical analysis of the results was conducted using the Statistica 8.0 software, considering the significance level $\alpha = 0.05$. In order to optimize the responses, the response surface methodology was used (Myers, Montgomery, & Anderson-Cook, 2009).

In order to concurrently optimize multiple responses, the global desirability function was used (Derringer & Suich, 1980), and the desirable aspects were: high yields, low moisture and high anthocyanin contents.

2.5. Paste and powder characterization

Açai pulp was characterized according to centesimal chemical composition (AOAC., 1997). The açai-maltodextrin paste was analyzed by solid concentration and density. Solid concentration was determined by the oven method at 105 °C until constant weight was reached. Density was determined using liquid pycnometry with a 25 mL glass pycnometer.

Açai powder was characterized by analysis of moisture content and anthocyanin content. In the optimal drying conditions the centesimal chemical composition (AOAC., 1997), median particle size, morphology, density and flowability, were analyzed, in order to verify the powder quality.

2.5.1. Moisture content

The moisture content was gravimetrically determined by the oven method at 105 ± 2 °C for 24 h (AOAC., 1997).

2.5.2. Total anthocyanin content

The total anthocyanin content was determined using the

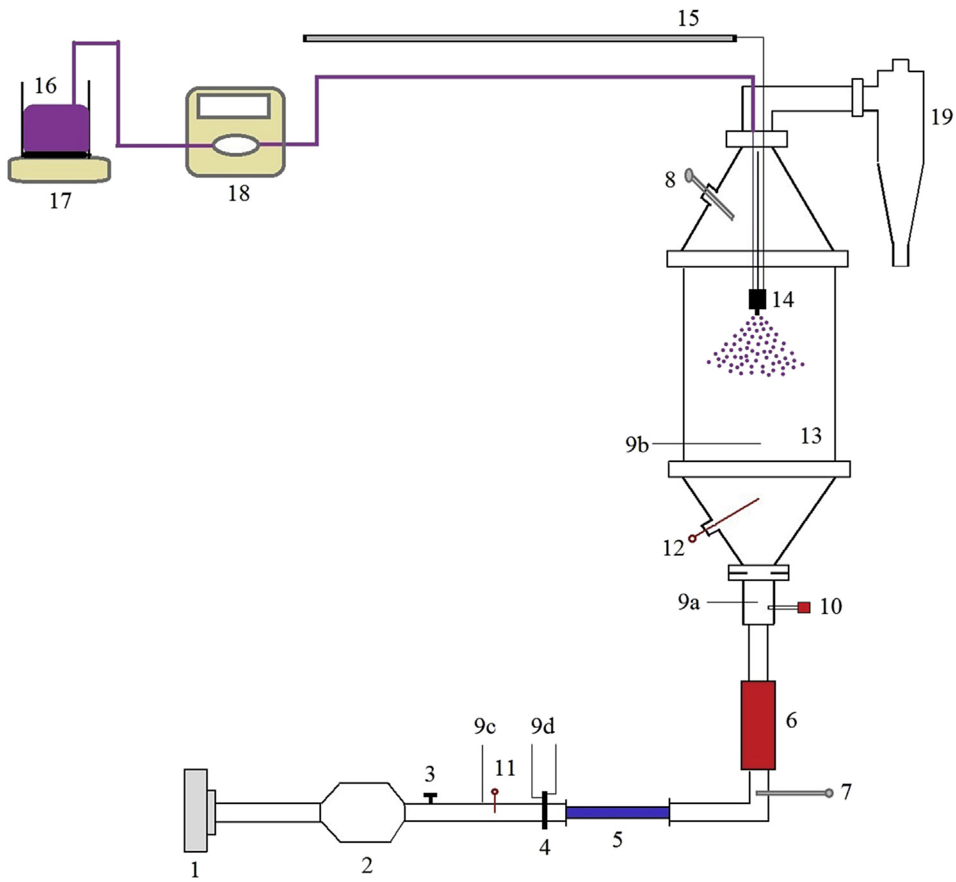

Fig. 1. Scheme of experimental apparatus. 1: Blower. 2: Cooler. 3: Control valve. 4: Orifice plate. 5: Silica bed. 6: Electrical heater. 7, 8: Thermo-hygrometers. 9: Pressure measure. 10, 11, 12: Thermocouples. 13: Spouted bed. 14: Spray nozzle. 15: Compressed air line. 16: Paste (açai-maltodextrin). 17: Magnetic stirrer. 18: Peristaltic pump. 19: Cyclone.

differential pH method described by Giusti and Wrolstad (2001). The absorbance (A) of the diluted samples was calculated according to Eq. (3), and the total anthocyanin content (AC) of açai powder was calculated according to Eq. (4).

$$A = (A_{510nm} - A_{700nm})_{pH1.0} - (A_{510nm} - A_{700nm})_{pH4.5} \tag{3}$$

$$AC(mg/100g) = \frac{A \times MW \times DF \times 1000}{\varepsilon \times l} \tag{4}$$

where MW is the molecular weight of the cyanidin-3-glucoside (449.2 g mol^{-1}); DF is the dilution factor; $\mathcal{E}$ is the molar absorbance of the majority anthocyanin (26.900 L mol^{-1} cm^{-1}); l is the path length in cm (1 cm) and 1000 is a factor for conversion from g to mg. Analyses were performed using an ultraviolet–visible spectrophotometer (UV–Vis), Spectrovision of Biosystems.

2.5.3. Median particle size and size distribution of the powder

The analysis of median particle size and size distribution of açai powder was conducted using the equipment Mastersizer S, model Long Bench-MAM 5005, Malvern, (Worcestershire, UK). For the reading, a small sample of the powder was immersed in isopropyl alcohol. This analysis were performed in duplicate.

2.5.4. Powder morphology

The morphology of the powder was analyzed using a scanning electron microscope (SEM), model LEO 440i, LEO Electron Microscopy (Cambridge, England, UK). The magnitudes analyzed were 100×, 500×, 1000× and 5000×.

2.5.5. Density of the powder

The density of the açai powder were determined using a helium gas pycnometer from Micromeritics, model Accupyc 1330 (Norcross, USA).

2.5.6. Powder flowability

The powder flowability was determined using an Autotap Instrument from Quantachrome Instruments, model DAT-4. The flowability of açai powder was analyzed in terms of Carr index (CI), calculated from the bulk (ρ *bulk*) and tapped (ρ *tapped*) densities, according to the Eq. (5) (Turchiuli, Eloualia, Mansouri, & Dumoulin, 2005).

$$CI = \frac{\left(\rho_{tapped} - \rho_{bulk}\right)}{\rho_{tapped}} \times 100 \tag{5}$$

3. Results and discussion

3.1. Characterization of the açai pulp and açai-maltodextrin paste

Açai pulp used showed moisture content of 83.82 ± 0.04 g 100 g^{-1} (wet basis), ashes 0.68 ± 0.02 g 100 g^{-1}, proteins 1.59 ± 0.04 g 100 g^{-1}, lipids 6.12 ± 0.10 g 100 g^{-1}, total fibers 1.80 ± 0.17 g 100 g^{-1}, total carbohydrates 7.77 ± 0.09 g 100 g^{-1}, and total energy 92.49 ± 0.47 kcal. The total anthocyanin content was 55.19 ± 0.22 mg 100 mL^{-1} (wet basis), expressed as cyanidin-3-glucoside. The average values for the density and solid concentration of the açai pulp were: 1026.42 ± 0.01 kg m^{-3} and 16 ± 0.37 g 100 g^{-1}, respectively. After dilution, the results were 1023.10 ± 0.01 kg m^{-3} and 11 ± 0.51 g 100 g^{-1}.

Maltodextrin was added in the açai diluted pulp at different proportions. Table 1 shows the physical paste (açai-maltodextrin) characteristics. It was verified that the addition of maltodextrin increased both the solids concentration and the density of the açai diluted pulp.

3.2. Experimental design–Statistical analysis

Through pressure drop curves, the airflow rate used in experimental design to assure spouted stability was determined. The curves obtained were similar to pressure drop curves showed by Marthur and Epstein (1974). The Qms found were 0.76 kg min^{-1}, 0.74 kg min^{-1} and 0.72 kg min^{-1}, for temperatures of 55, 65 and 75 °C, respectively.

Table 2 lists the real and codified values of the studies operating conditions and their respective experimental results. The statistical analysis of the results allowed the determination of the regression coefficients (Table 3) and the construction of a second-degree polynomial model, for each analyzed response. The determination coefficient (R^2) obtained for all the responses were adequate (>0.9067), indicating a good fit of the models regarding the experimental data obtained.

3.2.1. Influence of operating variables on process yield

In Table 2 it can be observed that the process yield showed considerable variation (from 26.59 % to 67.20 %), indicating that the changes in variables X_1, X_2 and X_3 caused a great influence in this response. This is confirmed by p-value (Table 3) and response surface (Fig. 2a), which showed that the process yield was positively influenced by all the independent variables studied. That is, increasing temperatures, airflow rate and maltodextrin concentration led to higher process yield.

The spouted bed is characterized by a high circulation rate of solid, presenting an intense movement of the particles, which allows to achieve a high level of contact between the gas vertically upwards and the solid particles. Thus, it is understood that the increase in temperature and supply airflow promote high rates of heat and mass transfer, which contributes to the drying of the açai and consequently increased formation of the powder. The increase in powder production due to the increase of air temperature was also observed by Souza (2009) in drying of tropical fruit pulp in a spouted bed. Butzge, Godoi, and Rocha (2014), observed the same when investigating the drying of a mix of the collagen and grape pulp in spouted bed.

Regarding to the influence of the concentration of maltodextrin in process yield, it is known that the maltodextrin aids in the powder formation and is widely used for obtaining fruit powder. The use of maltodextrin to obtain açai powder with good quality was indicated by Tonon Brabet, & Hubinger (2008), which dried açai pulp using a spray dryer. Fujita, Borges, Correia, Franco & Genovese, 2013 studied the drying of camu–camu pulp in spouted bed, and found that use of maltodextrine may protect the bioactive contents.

Therefore, higher process yield due to increased concentration of maltodextrin is probably related to the contribution of this additive for forming the powder and with increases the solids concentration of the paste. However, it is worth noting that this study aims to use the smallest possible addition of maltodextrin, in order to preserve as much as possible the açai pulp characteristics.

Table 2
Experimental design matrix with real and coded variables and experimental results.

Test	Independent variables			Response variables		
	T (X_1)	$Q \times Qms$ (X_2)	M (X_3)	Y	MC	AC
1	55 (−1)	1.2 (−1)	15 (−1)	26.59	5.40	203.47
2	55 (−1)	1.2 (−1)	25 (1)	34.95	4.90	145.09
3	55 (−1)	1.3 (1)	15 (−1)	50.43	4.77	146.15
4	55 (−1)	1.3 (1)	25 (1)	64.20	4.76	132.39
5	75 (1)	1.2 (−1)	15 (−1)	35.29	3.26	192.99
6	75 (1)	1.2 (−1)	25 (1)	56.77	3.23	167.74
7	75 (1)	1.3 (1)	15 (−1)	51.83	3.22	108.19
8	75 (1)	1.3 (1)	25 (1)	67.20	3.23	81.07
9	48.2 (−1.68)	1.25 (0)	20 (0)	30.57	5.77	156.19
10	81.8 (1.68)	1.25 (0)	20 (0)	52.78	3.29	194.26
11	65 (0)	1.16 (−1.68)	20 (0)	35.19	3.91	245.94
12	65 (0)	1.33 (1.68)	20 (0)	61.44	3.92	152.92
13	65 (0)	1.25 (0)	11.6 (−1.68)	27.46	4.28	186.11
14	65 (0)	1.25 (0)	28.4 (1.68)	66.88	4.79	156.27
15	65 (0)	1.25 (0)	20 (0)	52.62	3.80	267.32
16	65 (0)	1.25 (0)	20 (0)	53.10	3.62	265.62
17	65 (0)	1.25 (0)	20 (0)	52.99	4.57	269.82

T–drying air temperature (°C); $Q \times Qms$–product between air flow rate and minimal spouting flow (kg/min); M–maltodextrin concentration (%, w/w); Y–process yield (%); MC–moisture content (g 100 g^{-1} w.b.); AC–total anthocyanin content (mg 100 g^{-1} d b., expressed as cyanidin-3-glucoside).

3.2.2. Influence of operating variables on the moisture content of the powder

The temperature increase caused a decrease in açai final moisture content ($p < 0.05$), which varied from 3.22 g 100 g^{-1} to 5.40 g 100 g^{-1} (wet basis). The influence of temperature on powder moisture content can be clearly seen in Fig. 2b. In drying studies the air temperature is one of the input variables that most influences in the moisture content of the product. Therefore, it was expected that this variable showed strong influence on the moisture content of the acai powder produced by spouted bed. Wachiraphansakul and Devahastin (2007) observed the same in drying of okara in a spouted bed. Similar observations were made by Dotto, Souza, and Pinto (2011) when investigating chitosan drying in spouted bed.

3.2.3. Influence of operating variables on the anthocyanin content on the powder

The anthocyanins content was the response that shows the higher variations in the results, which ranged from 81.07 to 269.82 mg 100 g^{-1}, on a dry basis. This behaviour can be explained because the anthocyanins are unstable in the presence of heat being susceptible to degradation during the drying process.

In Table 3 it can be observed that all variables had negative effects on this response. Statistically, the airflow rate was the operational variable that most influenced in the anthocyanins degradation (Table 3). Probably, this is due to the fact that increases in airflow promotes a strong increase in the circulation of particles within the bed, and a greater contact with the drying air flow,

Table 1
Physical characteristics of the paste (açai-maltodextrin).

Property	Açai-maltodextrin (85–15%, w/w)	Açai-maltodextrin (80–20%, w/w)	Açai-maltodextrin (75–25%, w/w)
Density (kg m^{-3})	1039.40 ± 0.01	1089.70 ± 0.01	1062.70 ± 0.01
Solid concentration (g 100 g^{-1})	24.77 ± 1.35	28.93 ± 0.55	32.46 ± 1.39

Table 3
ANOVA for each response variable and coefficients for the prediction models.

Source	df	Process yield			Moisture content			Anthocyanin contents		
		Coef.	SS	p	Coef.	SS	p	Coef.	SS	p
Model	9	52.69	2896.07	<0.0001*	4.01	9.73	<0.0001*	269.55	45257.95	<0.0001*
X_1	1	5.29	382.26	0.0035*	−0.81	8.95	<0.0001*	−0.96	12.68	0.8941
X_2	1	9.10	1130.07	0.0001*	−0.06	0.05	0.5749	−29.15	11595.32	0.0042*
X_3	1	9.17	1148.69	0.0001*	0.02	0.01	0.8235	−12.80	2235.25	0.1094
X_1^2	1	−3.28	120.77	0.0457*	0.13	0.20	0.2705	−39.29	17354.45	0.0014*
X_2^2	1	−0.92	9.61	0.5159	−0.08	0.08	0.4657	−30.71	10605.11	0.0052*
X_3^2	1	−1.33	19.91	0.3575	0.13	0.20	0.2649	−40.72	18640.39	0.0011*
$X_1 X_2$	1	−3.26	85.28	0.0809	0.09	0.06	0.5139	−12.68	1286.51	0.2068
$X_1 X_3$	1	1.84	27.09	0.2883	0.06	0.03	0.6579	2.47	48.86	0.7942
$X_2 X_3$	1	−0.09	0.06	0.9579	0.07	0.04	0.6230	5.34	228.45	0.5762
Residual	7		143.65			0.97			4654.49	0.8941
Total	16		3039.72			10.70			49912.44	
R^2			0.9527			0.9091			0.9067	

Coef.: coefficient of model; df: Degrees of freedom; SS: Sum of squares.
*Statistically significant values ($p < 0.05$).

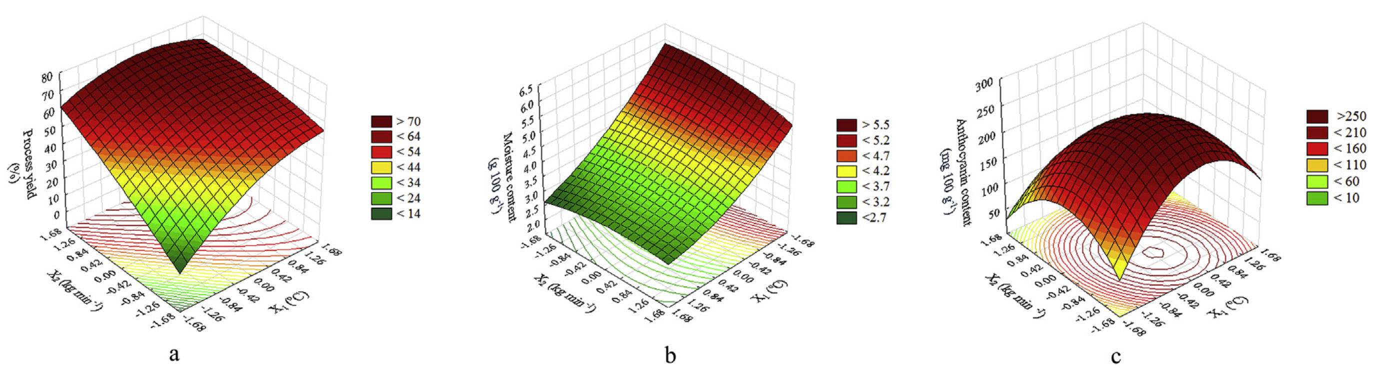

Fig. 2. Response surface of the (a) process yield for $X_3 = +1$; (b) moisture content for $X_3 = +1$; (c) anthocyanin content for $X_3 = -1$.

which promotes greater heat transfer rate and consequently greater anthocyanins degradation. In addition, increasing the airflow provides a greater amount of oxygen within the bed. The oxygen is also an accelerator of deterioration of anthocyanins, particularly when combined with high heat rates (Wrolstad, 2000).

In Table 3 it is noted that the lowest anthocyanins degradation were obtained when operating variables were kept at the central point (X_1, X_2 and $X_3 = 0$), which is clearly seen in Fig. 2c, where it can be observed an optimal region. The anthocyanins content obtained in this condition is around 269 mg 100 g^{-1}, that is higher than the values found by Tonon (2009) that evaluted acai powder produced in spray dryer (215.90 mg 100 g^{-1}).

The concentration of anthocyanins obtained in this study is also higher than the value of 50 mg 100 g^{-1} obtained by Gallori et al. (2004) and lower than the value 319 mg 100 g^{-1}, obtained by Schauss et al. (2006), who examined acai freeze-dried powder. Is important to highlight that Gallori et al. (2004) and Schauss et al. (2006) performed lyophilization of the pulp removal from açai fruit and not from frozen pulp, obtained commercially, like in the present study.

Therefore, the results indicate that although there have been degradation during the drying process, the quality of the powder formed is good, since it is above the açai powder produced by Tonon (2009), and can be compared with the quality of the acai powder lyophilized.

3.3. Global desirability

The concurrent optimization of multiple responses was conducted by the global desirability function analysis. A 30-point scale was used for each one of the three variables, and the values of exponents "s" and "t" were equal to 10 for the process yield and 1 for moisture and total anthocyanin content. Table 4 shows the values assigned to create high yields, low moisture and high anthocyanin concentration.

Fig. 3 illustrates the global desirability function obtained. It was verified that the function adequately meets the established characteristics, since it shows a global desirability coefficient equal to 0.9923, a value that is considered excellent (Lazic, 2004). Thus, the function may specify the levels of each one of the input values, allowing the spouted bed drying of açai to be maximized.

Eq. (6) was applied to transform the coded values (Xi) into real values (Vi). According to the experimental design, $\overline{V}$ is the average between the real value and δ is the distance between the real value in the central point and real value in the superior or inferior level of the variable.

$$X_i = \frac{V_i - \overline{V}}{\delta} \tag{6}$$

Therefore, the optimal conditions presented in Fig. 5 was: drying air temperature at 66 °C; airflow rate of 1.24 × Qms and maltodextrin concentration of 20.5% w/w.

3.4. Açai powder characterization

Açai powder obtained in the optimal conditions showed moisture content of 4.44 ± 0.15 g 100 g^{-1} (wet basis), ashes 1.55 ± 0.11 g

Table 4
Values assigned to the global desirability function.

Values assigned during optimization	Response variables		
	Process yield (%)	Moisture content (g 100 g^{-1})	Anthocyanin contents (mg 100 g^{-1})[a]
Low	26.59 (0)	3.22 (1)	81.07 (0)
Medium	46.85 (0)	4.49 (1)	175.44 (0)
High	67.20 (1)	5.77 (0)	269.82 (1)

(0): values considered unacceptable; (1): values considered desirable.
[a] Expressed as cyanidin-3-glucoside.

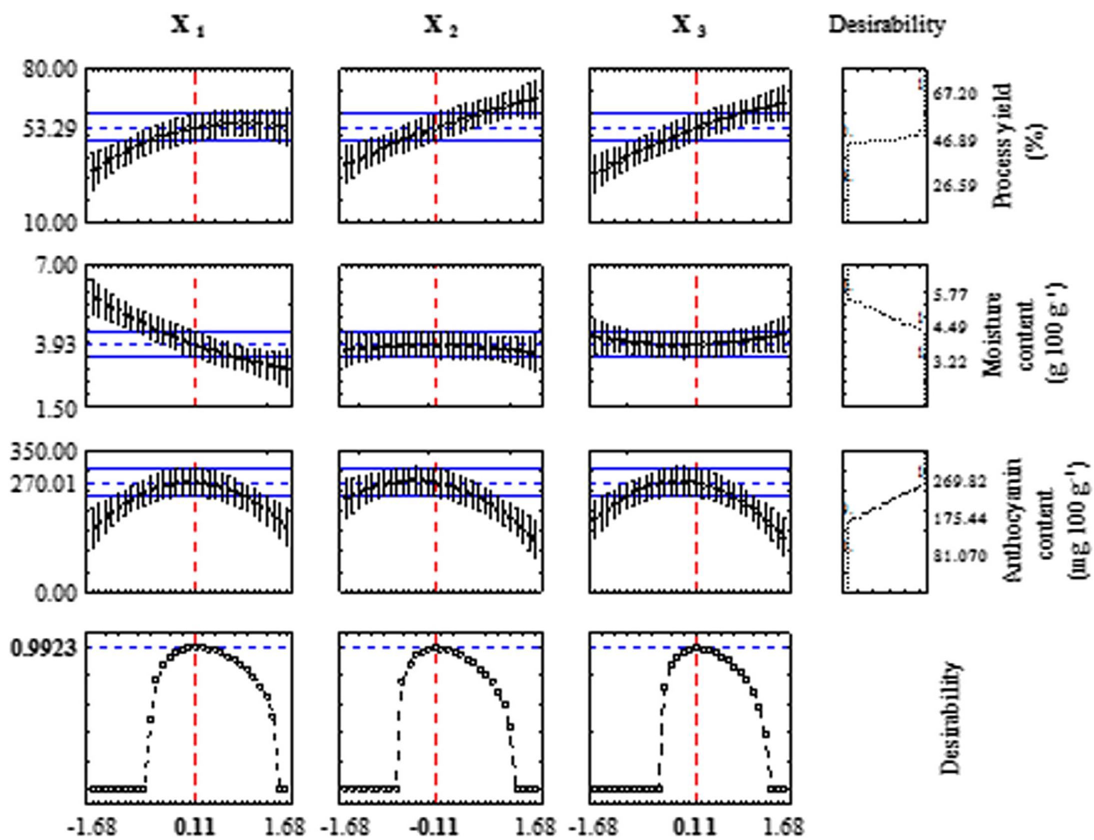

Fig. 3. Graphs of the desired function for the response variables process yield, moisture content and anthocyanin content.

100 g^{-1}, proteins 3.66 ± 0.01 g 100 g^{-1}, lipids 15.98 ± 0.27 g 100 g^{-1}, fibers 8.27 ± 0.12 g 100 g^{-1}, carbohydrate 78.82 ± 0.27 g 100 g^{-1}, and total energy 452.65 ± 1.42 kcal. From these values it is observed that the açai powder showed a total carbohydrate much higher than the açai pulp in natura. This is due to the characteristics of the pastes inserted in the bed, which had about 20.5% w/w of maltodextrin. Regarding to the ash, protein and fiber content it was found that the powder showed small decreases in the amounts of these components than the açai pulp. For the lipid content, it was observed that the powder has less fat than the pulp, and the lipid content reduced by half. Despite the observed losses caused by the drying process, the açai powders still a nutritious and energy product.

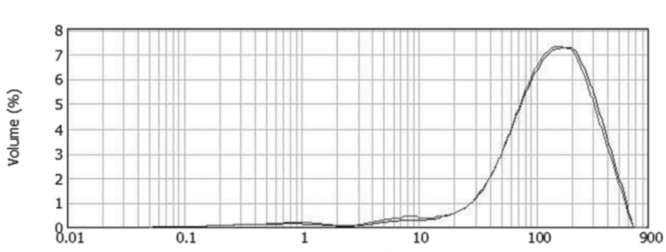

Fig. 4. Distribution of the particle size of açai powder produced under an optimal condition.

The total anthocyanin content of the powder was 269.38 ± 2.15 mg 100 g^{-1} (expressed as cyanidin-3-glucoside), a value close to the predicted by function desirability.

The size distribution of the açai powder obtained can be visualized in Fig. 4. The size distribution extends from at least 0.06 μm to at most 600 μm. The results showed that 50% of the particles have a mean diameter lower than 133.25 μm. The average values for the density of the açai powder were 1363 ± 0.01 kg m^{-3}. This powder showed excellent flowability (Turchiuli et al., 2005), since the CI value was 12.5% (<15).

Fig. 5 shows SEM of açai powder images. The images show that the açai powder is porous and has an irregular structure, and different shapes may be observed. This is probably associated with the mechanical deformity of the covering film due to the friction of particles amongst each other and the bed wall, which was also observed by Braga and Rocha (2013) during the drying of a milk-

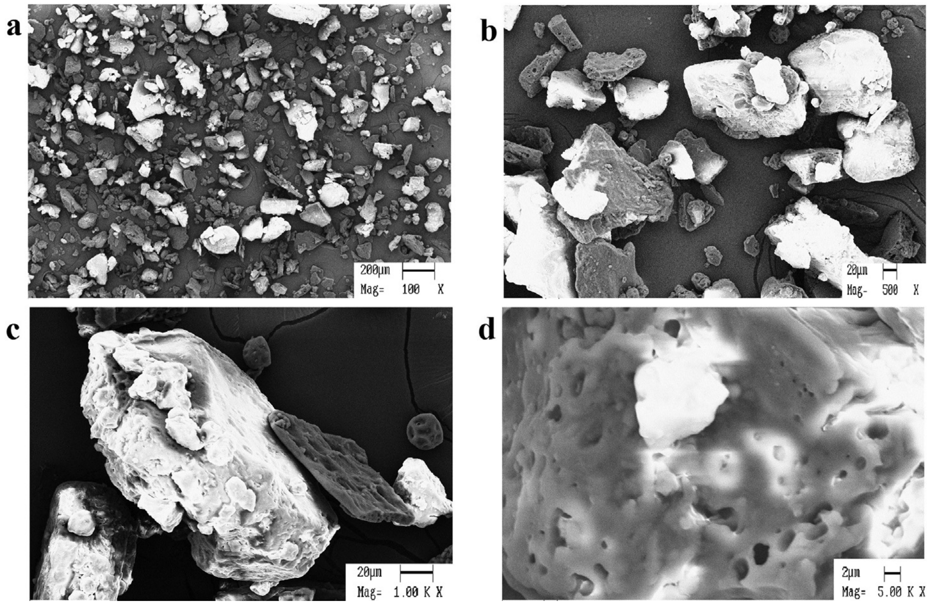

Fig. 5. Scanning electron microscopy images of açai powder produced at the optimal spouted bed drying condition; magnifications 100× (a), 500× (b), 1000× (c) and 5000× (d).

blackberry paste in spouted bed.

4. Conclusions

In this work, drying of açai in spouted bed was studied through evaluating the influence of operating conditions on the yield and quality of the product. The temperature increase caused an increase in process yield and decrease in powder moisture content. The airflow rate was the variable that most influenced the degradation of anthocyanins. The optimal drying condition found using desirability function method was: drying air temperature at 66 °C; airflow rate of $1.24 \times Qms$ and maltodextrin concentration of 20.5% w/w. In this condition a nutritious and energetic powder with low moisture content, high anthocyanin content, excellent flowability and a porous heterogeneous surface was obtained. Therefore, the acai powder produced in spouted bed represents good sources as antioxidants and energetic product and its application would be interesting to developing of functional foods.

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